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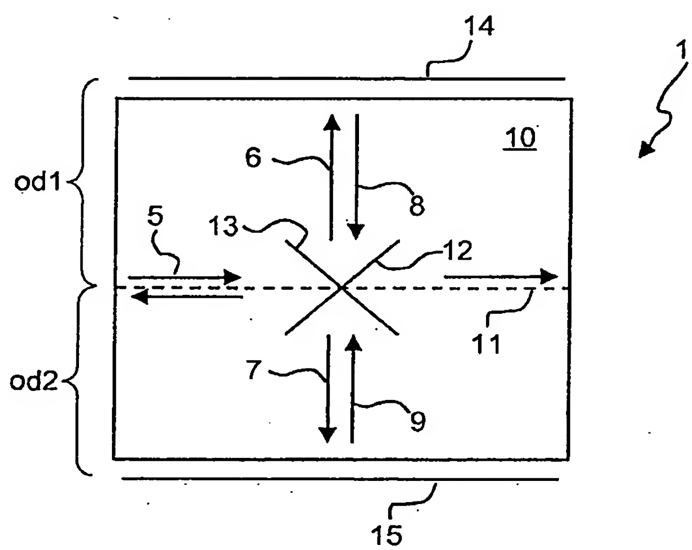
(54) Title: WAVELENGTH SELECTIVE OPTICAL DEVICE



(57) Abstract: This invention relates to an optical device for manipulating an optical signal propagating in a waveguide; and to a multiplexer, an attenuator and a modulator incorporating such device. A device according to the invention comprises two superimposed and tilted reflectors within the waveguide, which reflectors are arranged to deflect light out from the waveguide in two individual, substantially counter-propagating beams. The device according to the invention allows manipulation of individual channels within a wavelength dividion multiplexed optical signal. In a preferred embodiment, light is deflected out from the waveguide and into an external Fabry-Perot type resonator, which is tuned and adjusted in order to manipulate individual wavelengh regions of light. The invention also relates to a method for manipulating an optical signal, and to a method of tuning an optical device according to the invention.

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WAVELENGTH SELECTIVE OPTICAL DEVICE

Technical field

The present invention relates to an optical device for manipulating an optical signal propagating in a waveguide, such as an optical fibre. More particularly, the present invention relates to a highly versatile device capable of manipulating individual channels within a wavelength division multiplexed optical signal.

Technical background

In optical communications based on wavelength division multiplexing (WDM), information is sent through an optical waveguide, such as an optical fibre, on a multiplicity of wavelength channels simultaneously. Each wavelength channel propagate through the fibre independently of all other wavelength channels. By using WDM, very large data rates can be achieved.

However, as the number of wavelength channels increases, it becomes increasingly important to manipulate each individual channel separately.

Therefore, there is a need for devices and methods for manipulating individual channels within a wavelength division multiplexed optical signal.

Furthermore, the optical signals may propagate in either direction through the fibre, for which reason the operation of such devices and methods preferably should be invariant to the propagation direction of the signal.

Summary of the invention

It is an object of the present invention to provide an optical device for manipulating an optical signal propagating in a waveguide, such as an optical fibre, which optical device exhibits operational inversion symmetry with respect to the propagation direction of said

optical signal in said waveguide. In other words, it is an object of the present invention to provide a device for manipulating an optical signal, wherein the operation of the device is the same for both possible propagation directions of the optical signal through the waveguide.

The above-mentioned object is met by an optical device of the kind set forth in the appended claims.

An optical device according to the present invention for manipulating an optical signal propagating in a waveguide comprises a first and a second tilted reflector, which are provided in said waveguide. The first and the second reflectors are superimposed upon each other within the waveguide, and arranged to deflect light out from the waveguide into two beams having symmetrical propagation directions with respect to the waveguide (i.e. with respect to the propagation of light within the waveguide). In other words, the reflectors deflect light out from the waveguide in two different directions, which have the same angle with respect to the waveguide, i.e. light is deflected out from the waveguide symmetrically.

One advantage of an optical device according to the present invention is that spectrally selective manipulation of the optical signal is allowed, while at the same time operational inversion symmetry of the device is maintained.

Furthermore, an optical device according to the present invention can be used for manipulating individual wavelength channels within a wavelength division multiplexed optical signal.

Another advantage of an optical device according to the present invention is that it provides an optical device for manipulating an optical signal, which device is inherently cascadeable. In other words, any number of optical devices according to the present invention can be arranged in series in order to provide a cascaded structure for manipulating any number of wavelength channels simultaneously.

In the context of the present application, a tilted reflector is a reflector which has an inclination with respect to the propagation direction of light in the waveguide. Consequently, light incident upon the tilted reflector from the waveguide will have a non-normal angle of incidence, and will therefore be deflected away from its original propagation direction. Preferably, the inclination of the tilted reflector is such that light is deflected out from the waveguide. In a preferred embodiment, the angle of inclination of the tilted reflectors with respect to the propagation direction of light within the waveguide is close to 45 degrees, so that light is deflected out from the waveguide in a substantially normal direction (i.e. substantially perpendicularly out from the waveguide). Preferably, the tilted reflectors are comprised of blazed Bragg gratings. It is to be noted that the angle of deflection from a blazed Bragg grating is determined by the angle of the blaze and of the period of the grating. Perpendicular deflection can be obtained even if the tilt angle of the grating is different from 45 degrees with respect to the waveguide if the appropriate period is chosen.

In connection with the present invention, it is preferred that enhanced wavelength selectivity is provided by means of an external Fabry-Perot type resonator, the reflectors in the waveguide being operative to deflect at least some light into a resonant mode in said external resonator.

The Fabry-Perot type resonator is typically defined by at least two resonator mirrors. It is to be understood that said resonator mirrors may be comprised of any suitable structure for providing optical reflection, such as a metal layer, a dielectric stack or a distributed Bragg structure.

In one aspect, the present invention provides an optical device for selectively transmitting, in a forward-propagating direction, or reflecting back, in a

backwards-propagating direction, individual wavelength channels within a wavelength division multiplexed optical signal propagating in an optical fibre.

In another aspect, the present invention provides an optical device for manipulating individual channels within a wavelength division multiplexed optical signal, which device is inherently cascadeable. In other words, any number of devices can be arranged in series (in cascade) and thereby provide means for manipulating any number of channels simultaneously. In this aspect, the present invention provides a channel manipulation element for manipulation of individual channels within a wavelength division multiplexed optical signal.

In another aspect, the present invention can be used as an interferometer, since the present invention allows selective control of spectral resonance and phase relation.

In another aspect, the present invention can be used as a variable and spectrally selective optical attenuator. For example, any degree of transmission along the fibre can be achieved by appropriately altering the characteristics of the external Fabry-Perot type resonator.

In another aspect, the present invention can be used as a digital modulator for modulating individual channels within a WDM signal. Such modulation is rendered possible by the present invention at high speeds and with low dispersion. Further advantages are obtained by virtue of the device being wavelength tuneable. The device may also be used as a modulator for lasers.

In another aspect, the present invention can serve as an add/drop filter. Individual WDM channels may conveniently be added or dropped by a respective channel manipulation element. Any channel can be made either to be reflected back from the element or to be transmitted through the element along the fibre.

Yet another field of use for the optical device according to the present invention is in connection with fibre-to-fibre routers, where the present invention can provide channel exchange between two transmission fibres or fibre rings.

Operation that is invariant to propagation direction of the optical signal in the waveguide is achieved by utilising two superimposed tilted reflectors in the waveguide, which reflectors are arranged to deflect light out from the waveguide symmetrically, preferably perpendicularly to the propagation direction of the optical signal in the waveguide. As mentioned above, perpendicular deflection is achieved when the reflectors in the waveguide are oriented at an angle of substantially 45 degrees with respect to the propagation direction of light in the waveguide. In the case where the reflectors are comprised of blazed Bragg gratings, perpendicular deflection is provided by appropriate selection of blaze angle and grating period. Furthermore, high versatility, as well as new tuning capabilities are obtained by virtue of the two superimposed reflectors deflecting light out from the waveguide into two beams having symmetrical propagation directions with respect to the waveguide. Preferably, the deflected beams are substantially perpendicular to the waveguide.

By arranging an external Fabry-Perot type resonator outside of the waveguide, at least some of the light that is deflected out from said waveguide can be made to enter a resonant mode in said resonator. Such external resonator provides a useful means for manipulating individual wavelength channels within a (coarse or dense) wavelength division multiplexed optical signal, as will be elucidated in the following detailed description of some preferred embodiments. Also, enhanced tuneability is achieved by utilising an external resonator according to the above.

In a preferred embodiment of the present invention, the waveguide is an optical fibre, preferably a single mode fibre, and the reflectors comprise blazed Bragg gratings. Outside of the optical fibre, at least outside of the core of the fibre, there is arranged at least one Fabry-Perot type resonator comprised of two resonator reflectors (e.g. metal mirrors, dielectric stacks or distributed Bragg reflectors). The Fabry-Perot type resonator is oriented in such way that some of the light deflected out from the optical fibre by said reflectors will enter a resonant mode in said at least one resonator. The deflecting reflectors within the fibre have symmetric deflecting capabilities, so that light is deflected into two individual beams that are symmetrical with respect to said deflecting reflectors. In addition, the two deflected beams are preferably perpendicular to the optical fibre. In total, the arrangement constitutes a channel manipulation element according to the present invention.

When light is deflected perpendicularly out from the waveguide, a wavelength component (wavelength range) to which the external Fabry-Perot-type resonator is resonant will be deflected into a resonant mode in said resonator by the deflecting reflectors. Consequently, light propagating in the fibre and impinging upon the two superimposed reflectors will be coupled into the resonator and subsequently re-enter the optical fibre from the external resonator in either the forward-propagating direction or the backwards-propagating direction. Hence, incoming light is either reflected back from, or transmitted through, the channel manipulation element after having gone through a number of round-trips in the external resonator. By altering the characteristics of the external Fabry-Perot type resonator, light can selectively be controlled to reflect back from the device or to pass through the device. Furthermore, it is to be understood

that any ratio of reflection/transmission can be achieved by tuning the external resonator appropriately.

One way of tuning the spectral characteristics of the optical device according to the present invention is to alter the optical path length of the external resonator. By definition, the optical path length is equal to the actual physical path length times the refractive index of the medium traversed by light. Thus, a change of optical path length can be achieved by altering either the actual physical separation between the mirrors defining the resonator (or between the deflecting reflectors and either of the resonator mirrors), or by altering the refractive index of the medium between said mirrors. The refractive index of a medium can be altered, for example, by a temperature change, a change of electric field, or in the case where the medium is a semi-conductor, by a change in electron/hole concentration or by an electrically induced change of band gap. It is, of course, also possible to alter both the refractive index and the physical path length, if this is done appropriately. Different optical path lengths will, as commonly known in the art, cause light to experience different phase changes during a round-trip in the external resonator. Consequently, when the optical path length of the resonator changes, the resonator will become resonant to a different wavelength.

Another way of tuning the optical device according to the present invention includes altering of the separation between the waveguide (and hence the deflecting reflectors therein) and either or both of the resonator mirrors. Preferably, such tuning is performed while keeping the separation between the resonator mirrors essentially constant, the resonator thereby remaining resonant to essentially the same wavelength. By controlling the optical path lengths of the upper and the lower part of the resonator, respectively, the way in which light interfere when coupled back into the wave-

guide can be controlled. Consequently, coupling strength or attenuation of the optical device is controlled.

Yet another way of tuning the optical device according to the present invention includes tilting at least one of the resonator mirrors. There are two different ways of tilting the resonator mirror. The mirror can either be tilted parallel to the waveguide, or perpendicularly to the waveguide. When the mirror is tilted parallel to the waveguide, the resonant wavelength is shifted to a slightly different wavelength, and the resonance is broadened. When, on the other hand, the mirror is tilted perpendicular to the waveguide, the main effect is to reduce the coupling between the waveguide and the external resonator. By sufficiently tilting one of the resonator mirrors perpendicularly to the waveguide, the resonance of the resonator will be removed. Hence, the resonator will no longer be resonant and, consequently, manipulation of the corresponding channel within the optical signal in the waveguide is interrupted. Another possibility of tuning the device is to tilt both of the resonator mirrors, while keeping them essentially parallel to each other, i.e. while keeping the resonance in the external resonator. Light of a different wavelength will in this case be coupled into the resonant mode of the external resonator. It is to be noted that a slight adjustment of the separation between the mirrors might be necessary in this case.

Broad-band spectral selectivity of the device can be achieved by designing the reflectors inside the optical fibre to have a wavelength dependent reflectivity and/or by designing the mirrors of the Fabry-Perot type resonator to have wavelength dependent reflectivity. High-precision, narrow-band spectral selectivity is achieved by the etalon-effect of the Fabry-Perot type resonator. The combined effect of said broad-band and said narrow-band selectivity provides a highly versatile and spectrally selective device for manipulating individual chan-

nels within a WDM signal. As mentioned above, it is preferred that the deflecting reflectors comprise blazed Bragg gratings. In such case, it is straightforward to achieve spectral selectivity by designing the gratings to deflect any one predetermined wavelength range in a predetermined direction.

In some embodiments of the present invention, paired reflectors and external resonators are preferably used. Hence, for each wavelength channel there are two crossed and superimposed reflectors in the waveguide and two external Fabry-Perot type resonators. The motivation for utilising paired devices is that coherent mixing of signals, in a case when the same channel enters from both directions, is avoided. Although the paired elements are described as being discrete (separate entities), it is to be understood that a continuous structure may be used for the same purpose when gratings are employed as deflecting reflectors.

A preferred embodiment of the present invention comprises a plurality of cascaded channel manipulation elements, wherein different wavelength channels are manipulated by different elements. Preferably, for each channel, paired such elements are utilised, as has been briefly described above. Operatively connected to a length of fibre comprising the cascaded structure, there are provided two optical circulators, one at each side of the cascaded structure. By means of this embodiment, channels can be selectively interchanged between two fibre rings. The operation will be described in detail in the following description of preferred embodiments.

In another preferred embodiment, the present invention is used as a variable attenuator for individual channels within a WDM signal.

In yet another embodiment, the present invention is used as a modulator for optical communications.

Still further embodiments and applications are conceivable within the scope of the present invention, some

of which will be described below, other which are apparent to the man skilled in the art.

Brief description of the drawings

Further features and advantages of the present invention will be apparent from the following detailed description of some preferred embodiments thereof. In the detailed description, reference is made to the accompanying drawings, on which:

Figure 1 is a schematic illustration of an optical device according to the present invention having deflecting reflectors and an external Fabry-Perot type resonator,

Figure 2 is a schematic illustration of another optical device according to the present invention,

Figure 3 is a schematic illustration of the core of an optical fibre provided with reflectors in the form of superimposed, blazed Bragg gratings,

Figure 4 is a schematic illustration of two paired optical devices in transmitting mode, according to the present invention,

Figure 5 is a schematic illustration of two paired optical devices in reflecting mode, according to the present invention,

Figure 6 is a schematic illustration of a plurality of optical devices arranged in cascade for individually manipulating a plurality of wavelength channels simultaneously,

Figure 7 is a schematic illustration of a wavelength selective, dynamic attenuator according to the present invention,

Figure 8 is a schematic illustration of one method of tuning by tilting a resonator mirror,

Figure 9 is a schematic illustration of another method of tuning by tilting both resonator mirrors,

Figure 10 shows the filter characteristics of one type of tuning, and

Figure 11 shows the filter characteristics of another type of tuning.

On the drawings, like parts are designated like reference numerals.

Detailed description of preferred embodiments

A preferred embodiment of an optical device 1 according to the present invention is schematically shown in figure 1. In the figure, a cross section of a piece of optical fibre 10 is shown, the light guiding core 11 of which is schematically indicated by a broken line centrally in the piece of fibre 10. In the core 11 of the fibre 10, there is provided two superimposed reflectors 12 and 13. The two reflectors are oriented at right angles with respect to each other, in order to deflect light impinging upon the two superimposed reflectors into two anti-parallel beams. The device shown in the figure further comprises two external mirrors 14 and 15, forming an external Fabry-Perot type resonator. The resonator is positioned so that the deflecting reflectors 12, 13 are enclosed within the resonator. Furthermore, the deflecting reflectors and the external Fabry-Perot type resonator have such mutual orientations that at least some of the light deflected out from the core of the fibre enters a resonant mode in the resonator. By consequence, at least some of the light in any resonant mode in the resonator will also be deflected back into the core 11 of the fibre 10 by the crossed reflectors 12, 13. The device shown in figure 1 is sometimes referred to, in this specification, as a channel manipulation element.

The principle of action of the optical device 1 shown in figure 1 will now be described. In the figure, propagation direction of light is indicated by arrows. Note that the arrows have been displaced for clarity.

Assume that an optical signal is incident from the left in the figure (indicated by an arrow 5). Said signal will impinge upon the two superimposed reflectors 12, 13,

and part of the light within said optical signal is deflected upwards 6 by the first reflector 12 and part of the light is deflected downwards 7 by the second reflector 13. By virtue of the two reflectors being oriented at right angles with respect to each other, light deflected from the first 12 and the second 13 reflector respectively will form two anti-parallel beams 6 and 7. The formation of anti-parallel beams gives the device direction invariant properties, in that the same result would have been obtained if light was incident from the opposite direction, i.e. from the right in the figure.

Another important feature of the device according to the present invention is that two counter-propagating beams, which are incident upon the crossed reflectors, are split up into two respective components, whereby the two incident beams are superposed in each of the two deflected anti-parallel beams. This feature enables control of the interference in the two anti-parallel beams.

In the shown embodiment, at least some and preferably all of the deflected light enters a resonant mode in the external resonator. Therefore, the deflected light starts to circulate within the external resonator, and is eventually deflected back into the core of the fibre by the two reflectors 12, 13 in the fibre core 11. Obviously, it is crucial for the shown embodiment that the resonant mode and the superimposed reflectors in the fibre core overlap, at least partly. When light from the resonant mode in the external resonator is coupled back into the fibre core, this occurs in both propagation directions, since there are two reflectors of right angles with respect to each other.

It is to be noted that light 8 coming from the upper part of the external resonator is deflected into the fibre core 11 with a propagation direction to the left by the first reflector 12, and to the right by the second reflector 13. On the other hand, light 9 coming from the lower part of the external resonator is deflected into

the fibre core 11 with a propagation direction to the right by the first reflector 12, and to the left by the second reflector 13. Light in each respective propagation direction (i.e. left and right), after having been coupled back into the fibre core by the reflectors 12 and 13, is in fact a superposition of two components, one coming from the upper part of the external resonator and the other coming from the lower part of the external resonator.

Now, by selecting the characteristics of the external resonator such that light experience a different phase change in either the upper or the lower part of the resonator, as compared to the other, destructive interference can selectively be obtained either in the forward-propagating direction (to the right in the figure) or in the backwards-propagating direction (to the left in the figure). As known by the man skilled in the art, the phase change experienced by light is determined by the optical path length traversed. Therefore, the phase change can be altered by changing the length of actual physical path traversed, by changing the refractive index of the material through which light is propagating, or by a proper combination of the two.

More specifically, referring again to figure 1, let the optical path length between the upper resonator mirror 14 and the crossed reflectors 12 and 13 be od1, and let the optical path length between the lower resonator mirror 15 and the crossed reflectors 12 and 13 be od2. For any fixed value of od1 and od2, the Fabry-Perot type resonator is resonant to a corresponding wavelength (or a set of discrete wavelengths if no additional filtering is employed), as determined by the cavity condition. As known in the art, the cavity condition (the expression determining resonant wavelengths) is $2(od0)=m\lambda$, where $od0=od1+od2$ and m is an integer. Thus for a resonant mode, the round-trip path length must be an integer number of wavelengths. Stated differently, for a resonant

mode there must be a constant constructive interference within the resonator, i.e. the resonator must support a standing wave at the resonant wavelength. Consequently, as long as od0 is held constant, the Fabry-Perot type resonator will remain resonant to the same wavelength.

Recall now that, according to the present invention, light is coupled out from the external resonator both when coming from the upper portion of the resonator and when coming from the lower portion of the resonator. Therefore, in each propagation direction in the waveguide (left and right), there will be a superposition of light from the upper and the lower portion of the resonator. Whether constructive or destructive interference is obtained is determined by the phase relation between light from the upper portion and light from the lower portion. The phase relation, in turn, is determined by the optical path lengths od1 and od2 of each respective portion of the resonator. Consequently, constructive interference is any desired direction to any desired degree can be achieved by appropriately controlling the optical path lengths od1 and od2, allowing any ratio between transmission and reflection at the optical manipulation element.

It is to be noted that, if the degree of transmission (reflection) of the element is to be adjusted without changing the wavelength to which the resonator is resonant, od1 and od2 must be changed while keeping od0 constant (i.e. a lateral translation of the external resonator). Lateral translation means a translation perpendicularly to the longitudinal direction of the waveguide.

In figure 2, another embodiment of an optical device according to the present invention is shown. In this case, light is not deflected out from the waveguide perpendicularly, but at another angle. Note, however, that the deflected beams are still symmetrical with respect to the longitudinal direction of the waveguide.

In the shown embodiment, light cannot be coupled back in the waveguide in the counter propagating direction. However, the embodiment shown in figure 2 is preferred when a channel within a WDM signal is to be manipulated for attenuation or modulation.

The deflecting reflectors shown in figure 2 are comprised of crossed Bragg gratings which have equal periods and equal but opposite blaze angles. In this way, light is deflected symmetrically out from the waveguide. As mentioned above, the deflection angle from a blazed grating is determined by both the blaze angle and the period. Hence, a predetermined deflection angle can be achieved by appropriate selections of period and blaze angle.

A preferred embodiment of the tilted reflectors is schematically shown in figure 3. Here, the reflectors are comprised of blazed Bragg gratings 21, 22. Each blazed Bragg grating is comprised of a periodic structure of refractive index variations, which are inclined with respect to the propagation direction of light within the waveguide (i.e. the grating is blazed). Consequently, the blazed gratings are, in fact, tilted reflectors. The characteristics of blazed Bragg gratings are commonly known in the art. Each of the blazed gratings 21 and 22 shown in figure 3 are arranged to deflect light of a predetermined wavelength out from the waveguide perpendicularly. Hence, it can be said that the blazed gratings are arranged at right angles with respect to each other. In effect, light from the waveguide, which light is incident upon the two blazed gratings, will be perpendicularly deflected out from the waveguide in two opposite directions, i.e. in two beams that are symmetrical with respect to the blazed gratings. In this case, the deflected beams are essentially anti-parallel to each other and perpendicular to the waveguide.

In an optical communications system based on transmission of signals through optical fibres, there is an

obvious chance that the same wavelength range is utilised for transmission of two different signals, one in each direction, i.e. in two counter-propagating directions. This situation is handled according to the present invention by employing paired channel manipulation elements, as schematically shown in figures 4 and 5. In figure 4 and 5, the propagation direction of light signals are indicated by arrows. Note, however, that the arrows have been displaced for clarity in the figures. It is to be understood that these paired elements can be comprised of one continuous element comprising a blazed grating, wherein a first and a second portion of the continuous element constitute each constituent of the pair, respectively.

If only one channel manipulation element according to the above would have been used in a situation as described above, the resonant mode in the external resonator could comprise a mixture of said two signals. When, in that case, light from the external resonator is coupled back into the core of the optical fibre, there is an ambiguity regarding to which signal the light actually belong. Therefore, in order to avoid coherent mixing of two counter-propagating signals, it is preferred to utilise two essentially identical elements 1, one for each of said signals. When operating in reflecting mode as shown in figure 5, i.e. when light of the wavelength range at issue is primarily back-reflected from each of the paired elements, there will be essentially no light of said wavelength range between the two pairs of crossed deflecting reflectors, whereby coherent mixing of the signals is avoided.

Another embodiment of the present invention is schematically shown in figure 6. Several channel manipulation elements 1 are arranged in cascade along a length of optical fibre. The shown embodiment is an add/drop multiplexer for exchanging channels between two different transport fibres or fibre rings 41 and 42. The

shown multiplexer can be incorporated into an optical fibre-to-fibre router.

For each wavelength channel Ch.1 to Ch.5, there is provided one pair each of elements 1.1 to 1.10, as such shown in figures 4 and 5. Paired elements are utilised in order to avoid coherent mixing of channels. Five such pairs (one for each respective channel Ch.1 to Ch.5) are shown in the figure, the multiplexer as shown thereby being designed for WDM communications on five channels. However, it is to be understood that any number of paired elements can be cascaded in order to provide a multiplexer for any number of wavelength channels.

Although the channel manipulation elements have been described as having a respective set of crossed deflecting reflectors, it is also possible to implement the deflecting reflectors as crossed, blazed gratings without any actual division between the reflectors of different elements. Different portions of the chirped gratings will then act as reflectors for different elements.

Consider now a first optical signal comprised of five wavelength channels in the first fibre ring 41 and a second optical signal, also comprised of five wavelength channels, in the second fibre ring 42. Each of said rings is connected to the length of fibre comprising the cascaded and paired elements 1.1 to 1.10 by means of a respective optical circulator 43, 44. In this case, it is required that the manipulation elements operate on the zeroth order of deflected light, i.e. that the deflection of light from the waveguide is performed perpendicularly. Consequently, any light reflected back from the cascaded elements 1.1 to 1.10 will continue to propagate in the original fibre ring (41 or 42, depending on its origin). Now, an exchange of one channel between the two fibre rings is to be executed. Initially, when no exchange of channels is to be executed, each of the pairs in the cascade operates in reflection mode as shown in figure 5, i.e. acts to reflect the corresponding channel back

towards each respective circulator. In order to exchange any of the five channels between the two fibre rings, the appropriate pair of the cascaded elements is switched to transmission mode. As a result, the channel corresponding to the pair operating in transmission mode is passed on to the other fibre ring - a channel exchange has been performed.

Assume, for example, that channel number 2 (Ch.2) is to be exchanged between the two fibre rings. Then, all pairs of elements are operated in full reflection, i.e. acting to couple light back in a backwards-propagating direction with respect to the incident direction, except the pair corresponding to the channel to be exchanged, which pair operates in transmission mode. Thus, in this example of exchanging Ch.2, elements 1.3 and 1.4 are switched to transmission mode. Consequently, in the signal in the first fibre ring 41, channels Ch.1, Ch.3, Ch.4 and Ch.5 are back-reflected by the cascaded structure towards the optical circulator 43, and are thereby directed to the output port for further propagation in the fibre ring 41. In addition, the wavelength channel Ch.2 is received from the second fibre ring 42, which channel is interleaved with the other channels in ring 41. For the signal in the second fibre ring 42, similar interleaving takes place for channel Ch.2 from the first ring 41.

Furthermore, any number of channels can be exchanged simultaneously by switching the appropriate pairs to transmission mode. In fact, the entire optical signal in each of the fibre rings can be exchanged simultaneously by switching all pairs to transmission mode.

A similar configuration can be operated as a wavelength selective, dynamic attenuator, as shown in figure 7. In this case, however, the elements need not be paired, since light is only propagated in one direction through the fibre at any one instant. For the same reason, an optical circulator 51 is only necessary at the input side.

As has been discussed in the introduction, any partition between reflection and transmission of a channel can be obtained by controlling the external Fabry-Perot type resonator, i.e. any ratio of transmission/reflection is possible. Thus, light deflected out from the core of the optical fibre can be manipulated such that any degree of transmission through the element is obtained when light is coupled back into the core 11 from the external resonator. This feature is employed in order to provide the dynamic attenuator.

If no attenuation is desired, an optical signal coming from the circulator 51 at the input side and entering the length of fibre comprising the channel manipulation elements 1.1 to 1.10 is passed on to the second fibre by operating all elements 1.1 to 1.10 in full transmission as shown in figure 4. When attenuation is required for any of the channels, the corresponding element is controlled to provide a desired amount of attenuation by reflecting some light back towards the optical circulator 51 at the input side. Light reflected back is then passed on by the circulator to a dump output. Light at the dump output may simply be thrown away, or may be measured and analysed for monitoring purposes.

The arrangement shown in figure 7 can also be operated as a digital modulator for modulating channels within a WDM optical signal. In that case, the attenuator is operated so that light is either transmitted entirely or reflected entirely. Hence, a continuous wave carrier signal that is input from the input circulator 51 can be conveniently modulated by the arrangement shown in figure 7.

Alternative methods of tuning the optical device according to the present invention are schematically shown in figures 8 and 9. The illustrated methods are based on tilting of at least one of the resonator mirrors, in order to alter the resonance characteristics of the device.

Referring to figure 8, tuning of the device 1 can be performed by tilting one of the resonator mirrors 14 parallel to the waveguide, such that the two resonator mirrors are no longer parallel to each other. Tilting parallel to the waveguide means that the mirror is pivoted about an axis perpendicular to the waveguide. Consequently, the length of the external resonator will vary along the same. Hence, the shape of the filter function will be broadened and shifted towards longer wavelengths. This adjustment of the filtering is schematically shown in figure 10, in which the initial filter function is illlustrated by a solid line, and the filter function at tilted resonator mirror is illustrated by a broken line.

In figure 9, another method of tuning by tilting the resonator mirror 14 is illustrated. In this case, the resonator mirror is tilted perpendicularly to the longitudinal direction of the waveguide (the mirror is pivoted about an axis parallel to the waveguide. Hence, the finesse and the quality of the external Fabry-Perot type resonator will be lowered, since less light is coupled back from the resonator into the waveguide when the resonator mirror is tilted in this manner. The resonant wavelength, however, will remain substantially the same. In effect, the filter function is still broadened, but with a maintained centre wavelength. Effectively, this type of tuning can be used for modulating the amplitude of the channel to which the external resonator is resonant. This adjustment of the filtering is schematically shown in figure 11, in which the initial filter function is illlustrated by a solid line, and the filter function at tilted resonator mirror is illustrated by a broken line.

In conclusion, the present invention provides an optical device for manipulating individual channels within a WDM optical signal, which optical device is

tuneable, controllable and configurable, as well as direction invariant as regards propagation of the signal to be manipulated. Furthermore, the inherent possibility to cascade elements according to the present invention provides a virtually unlimited scalability, and may therefore be utilised even if a very large number of wavelength channels are used in a WDM communications system.

Although specific embodiments are presented in the detailed description above, it is to be understood that the present invention can be implemented differently than described. The detailed description of embodiments is not intended to limit the scope of the invention as defined in the claims.

CLAIMS

1. An optical device for manipulating an optical signal propagating in a waveguide, comprising

a first tilted reflector arranged in said waveguide, and

a second tilted reflector arranged in said waveguide,

wherein said first and said second tilted reflectors are superimposed upon each other, and arranged to deflect light out from said waveguide into two individual beams.

2. An optical device as claimed in claim 1, wherein the first and the second reflectors are arranged to deflect light at equal angles with respect to the propagation direction of light within the waveguide, but in opposite directions.

3. An optical device as claimed in claim 1 or 2, further comprising a Fabry-Perot type resonator defined by at least two resonator mirrors, the first and the second tilted reflectors being positioned within said resonator and arranged to deflect light into a resonant mode in said resonator.

4. An optical device as claimed in claim 3, wherein the resonator mirrors defining the Fabry-Perot type resonator are arranged outside of the waveguide.

5. An optical device as claimed in claim 3 or 4, wherein each resonator mirror comprises a reflecting metal layer.

6. An optical device as claimed in claim 3 or 4, wherein each resonator mirror comprises a reflecting dielectric stack.

7. An optical device as claimed in claim 3 or 4, wherein each resonator mirror comprises a distributed Bragg reflector.

8. An optical device as claimed in any one of the claims 3 to 7, wherein at least one of the resonator mirrors has high reflectivity only for light within a predefined wavelength region, so that the Fabry-Perot type resonator is resonant only to light within said predefined wavelength region.

9. An optical device as claimed in any one of the preceding claims, wherein each tilted reflector comprises a blazed Bragg grating.

10. An optical device as claimed in claim 9, wherein the blazed Bragg grating has a period such that light within a predefined wavelength range is deflected out from the waveguide.

11. An optical device as claimed in claim 3, further comprising means for changing the optical distance between at least one of the two mirrors of the Fabry-Perot type resonator and the superimposed first and second reflectors.

12. An optical device as claimed in any one of the claims 3 to 11, further comprising means for tilting at least one of the two mirrors of the Fabry-Perot type resonator.

13. An optical device as claimed in claim 11, wherein the means for changing the optical distance is operative to displace at least one of the two mirrors.

14. An optical device as claimed in claim 11, wherein the means for changing the optical distance is operative to change a refractive index between the two mirrors.

15. An optical device as claimed in any one of the preceding claims, wherein the waveguide is a planar waveguide.

16. An optical device as claimed in any one of the claims 1 to 14, wherein the waveguide is an optical fibre.

17. A method of manipulating an optical signal propagating in a waveguide, comprising the steps of

laterally extracting at least part of the light of said optical signal from said waveguide in two individual beams,

controlling the phase of at least one of said two individual beams, and

bringing the extracted light back into said waveguide for further propagation along the same.

18. A method as claimed in claim 17, further comprising the step of

directing the two individual beams into an external resonator,

wherein the step of controlling the phase is performed by means of said external resonator.

19. A method as claimed in claim 18, wherein the step of controlling the phase is performed by controlling the optical path length in at least a portion of the external resonator.

20. A method as claimed in any one of the claims 17 to 19, wherein the step of extracting is performed by means

of a first and a second deflecting reflector provided in the waveguide.

21. A method as claimed in claim 20, wherein the first and the second deflecting reflectors are further used for performing the step of bringing the extracted light back into the waveguide.

22. A method as claimed in claim 19, wherein the optical path length is controlled by controlling the geometrical path length.

23. A method as claimed in claim 19, wherein the optical path length is controlled by controlling a refractive index in at least a portion of the external resonator.

24. A method of tuning the resonant wavelength of an optical device as defined in any one of the claims 3-8, comprising the step of controlling the optical path length between the two resonator mirrors of the Fabry-Perot type resonator.

25. A method as claimed in claim 24, wherein the step of controlling the optical path length is performed by controlling the geometrical distance between the resonator mirrors.

26. A method as claimed in claim 24, wherein the step of controlling the optical path length is performed by controlling a refractive index between the resonator mirrors.

27. A method as claimed in claim 26, wherein the refractive index is controlled by controlling temperature.

28. A method as claimed in claim 26, wherein the refractive index is controlled by controlling electron/hole concentration in a semi-conductor material.

29. A method as claimed in claim 26, wherein the refractive index is controlled by means of an applied electric field.

30. A method of tuning an optical device as defined in any one of the claims 3-8, comprising the step of controlling the optical path length between the tilted reflectors and each of the resonator mirrors, respectively.

31. A method as claimed in claim 30, wherein the separation between the resonator mirrors is kept essentially constant.

32. A method as claimed in claim 30 or 31, wherein the step of controlling the optical path length between the tilted reflectors and either of the resonator mirrors is performed by controlling the geometrical distance.

33. A method as claimed in claim 30 or 31, wherein the step of controlling the optical path length between the tilted reflectors and either of the resonator mirrors is performed by controlling a refractive index between said resonator mirrors.

34. A method as claimed in claim 33, wherein the refractive index is controlled by controlling temperature.

35. A method as claimed in claim 33, wherein the refractive index is controlled by means of an applied electric field.

36. A method as claimed in claim 33, wherein the refractive index is controlled by controlling a band gap in a semi-conductor material.

37. A method of tuning an optical device as defined in claim 12, comprising the step of tilting at least one of the resonator mirrors with respect to the waveguide.

38. A method as claimed in claim 37, wherein the resonator mirror is tilted parallel to the longitudinal direction of the waveguide..

39. A method as claimed in claim 37, wherein the resonator mirror ia tilted perpendicular to the longitudinal direction of the waveguide.

40. An optical add/drop multiplexer comprising

a length of optical fibre arranged between a first and a second optical circulator,

wherein said length of fibre comprises at least one optical device as defined in any one of the claims 3-8,

said device being operative to selectively transmit or reflect an associated wavelength channel,

and wherein each of said circulators is operative to direct light from an input terminal into said length of optical fibre, and to direct light from said length of optical fibre to an output terminal.

41. An optical multiplexer as claimed in claim 40, comprising a plurality of optical devices arranged in cascade, each of said devices being operative to selectively transmit or reflect a respective associated wavelength channel.

42. A wavelength selective, variable attenuator comprising

a length of optical fibre having an input end and an

output end,

said length of fibre comprising at least one optical device as defined in any one of the claims 3-16, which device is controllable to provide a desired level of transmission of light within said length of optical fibre.

43. An attenuator as claimed in claim 42, further comprising an optical isolator that is operatively connected to the input end of the length of fibre.

44. An attenuator as claimed in claim 42, further comprising an optical circulator that is operatively connected to the input end of the length of fibre.

45. An attenuator as claimed in any one of the claims 42 to 44, wherein the at least one optical device is adjustable between full transmission and zero transmission, in order to allow digital modulation of a carrier wavelength delivered to the input end of the fibre to provide a modulated output..

46. A modulator for lasers comprising at least one optical device as defined in any one of the claims 3-8 provided in a resonant cavity of a laser, which device is configured to transmit a desired resonance wavelength.

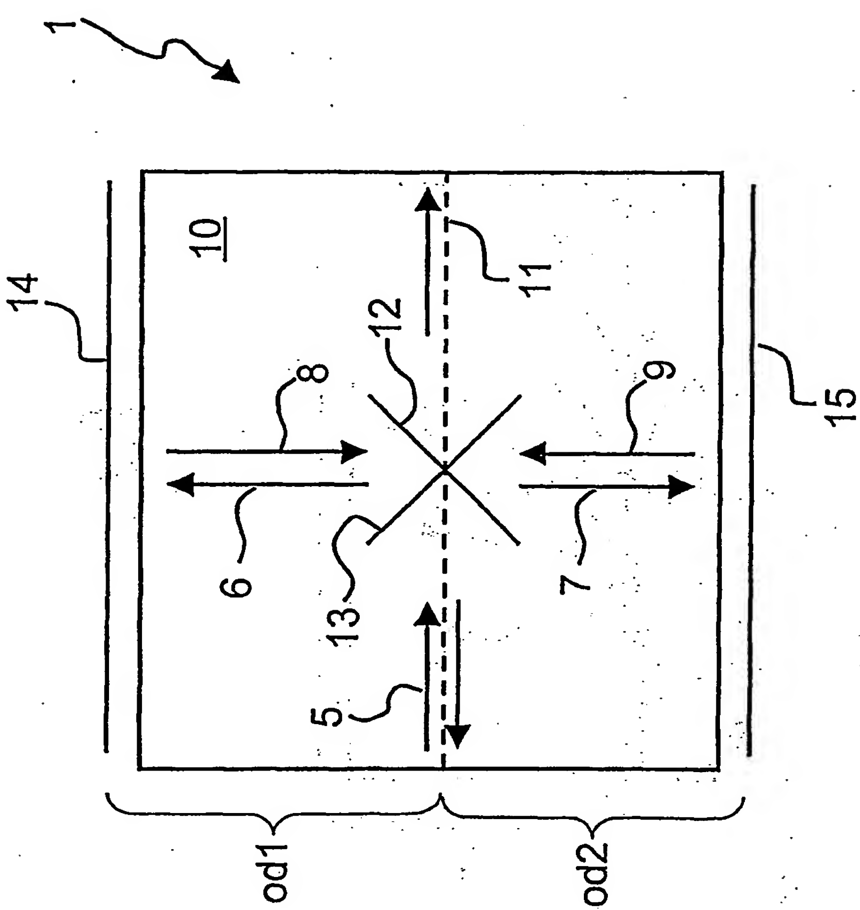


Fig. 1

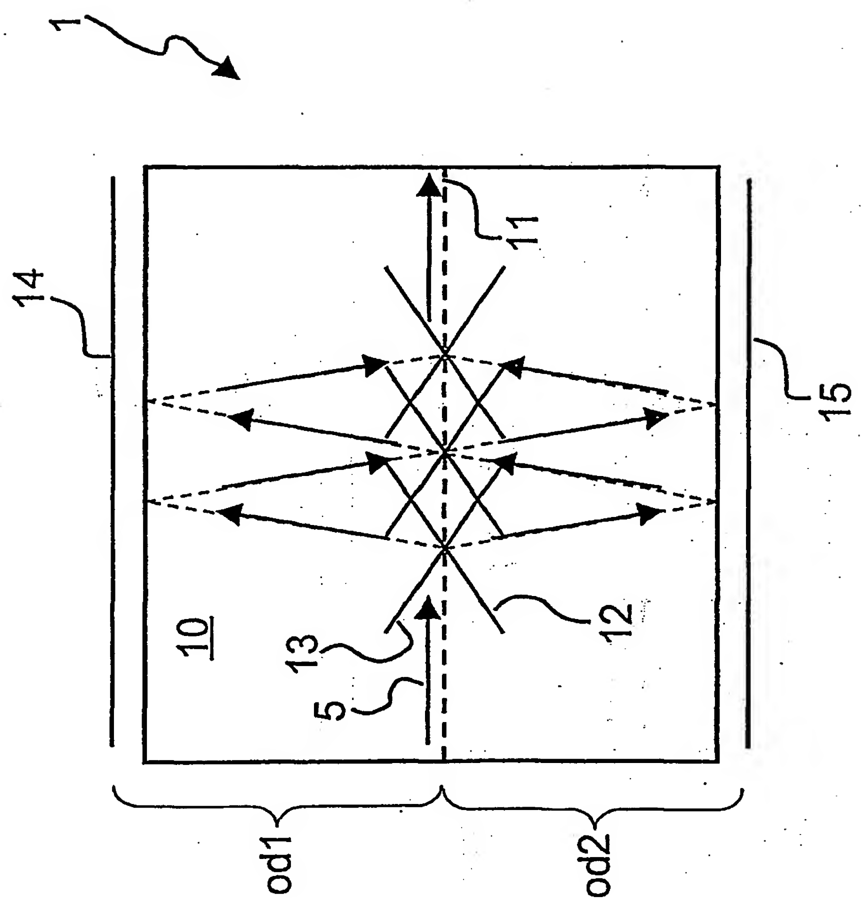


Fig. 2

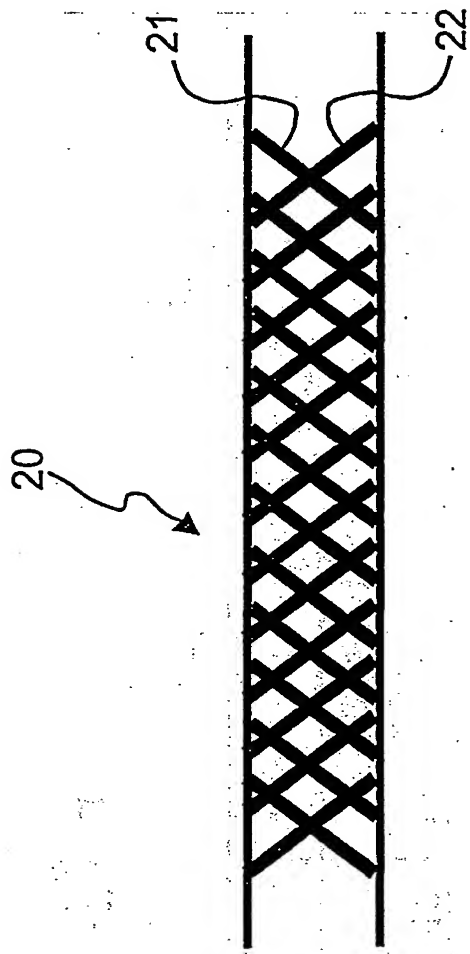


Fig. 3

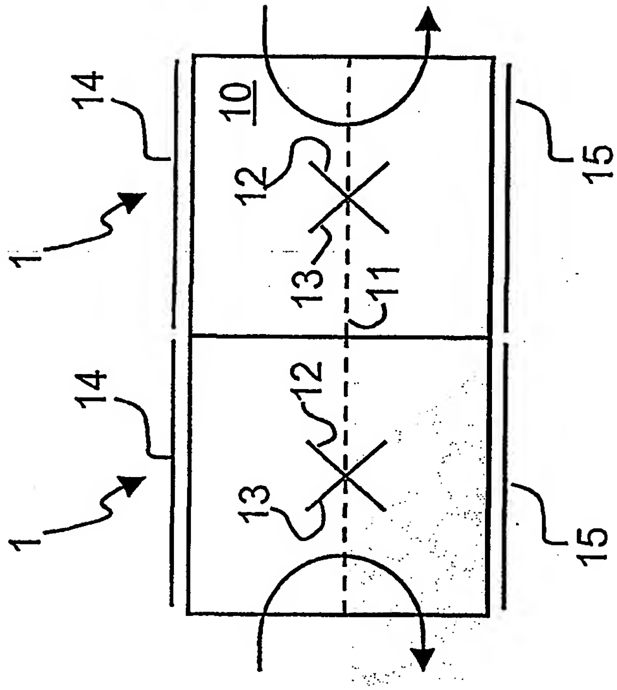


Fig. 5

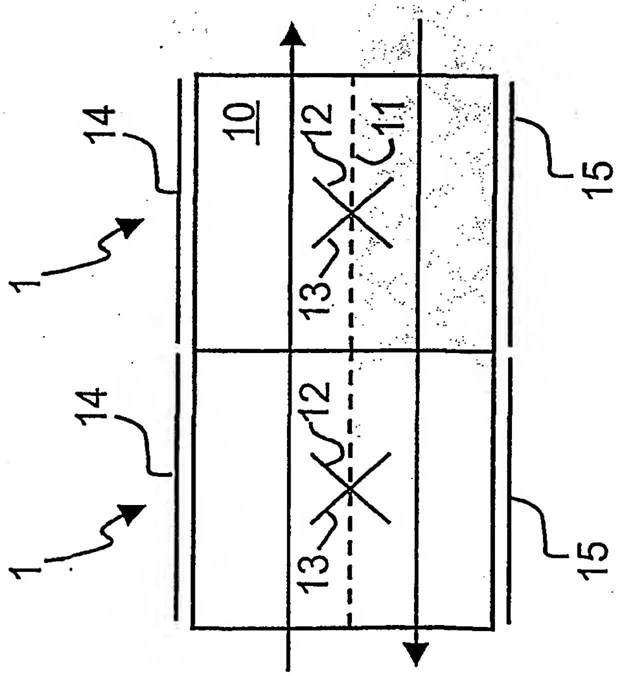
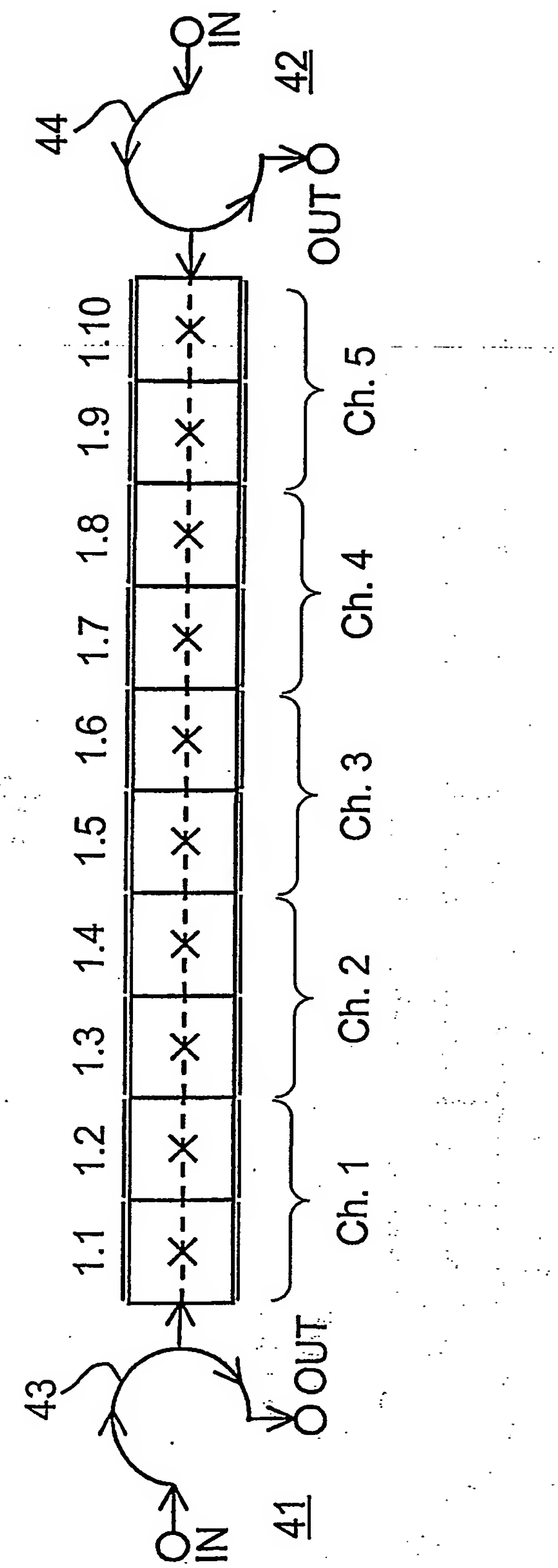


Fig. 4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44
OUT
1.10
1.9
1.8
1.7
1.6
1.5
1.4
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1.1
Ch. 5
Ch. 4
Ch. 3
Ch. 2
Ch. 1
OUT
43
IN
41

Fig. 6

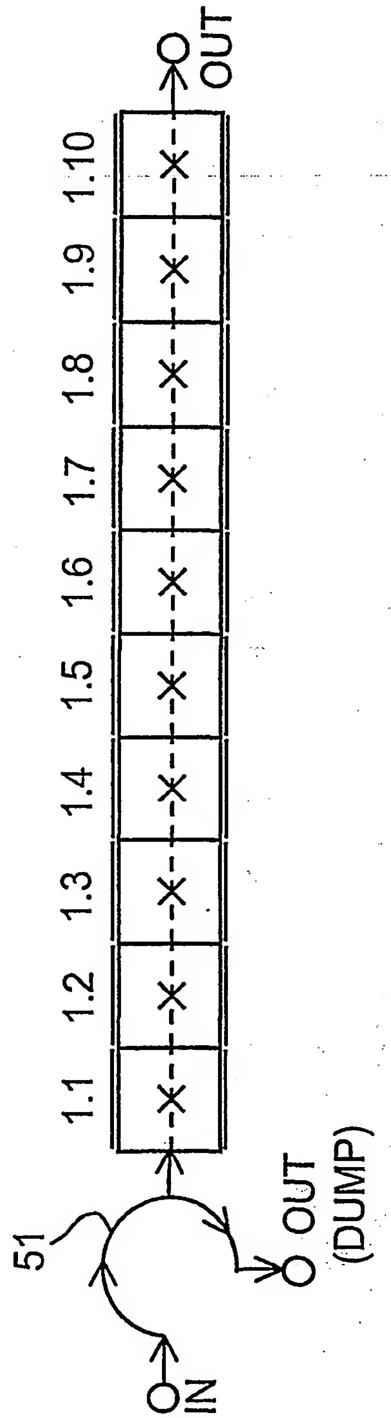

Fig. 7

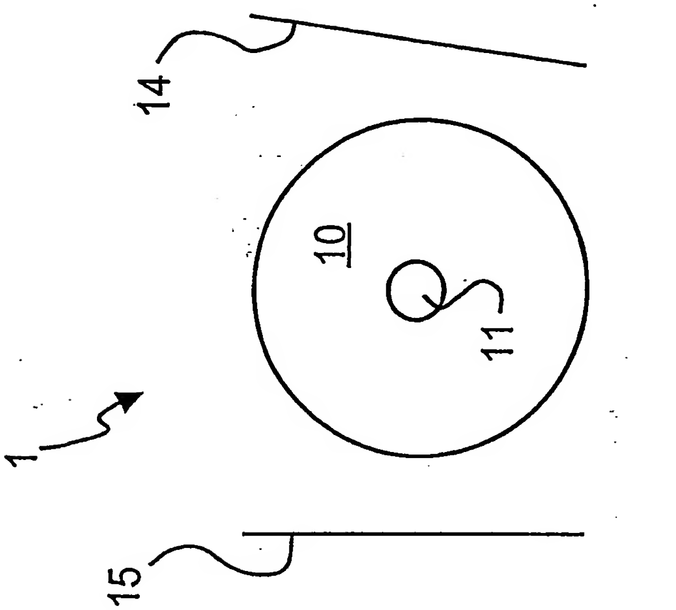

Fig. 9

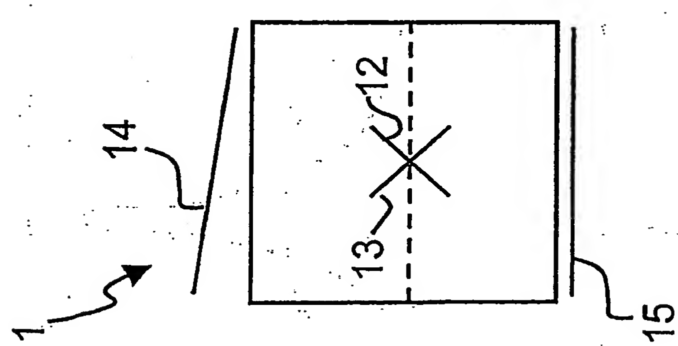

Fig. 8

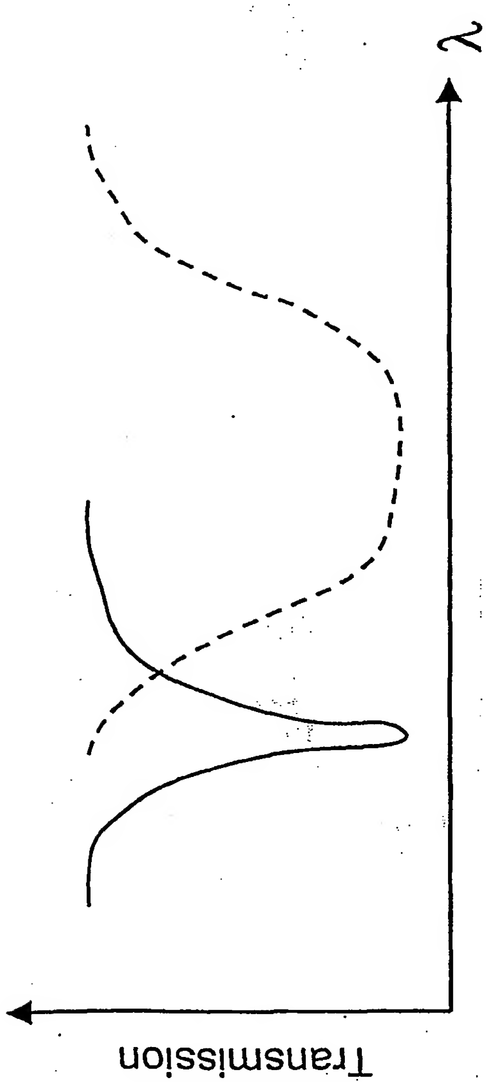

Fig. 10

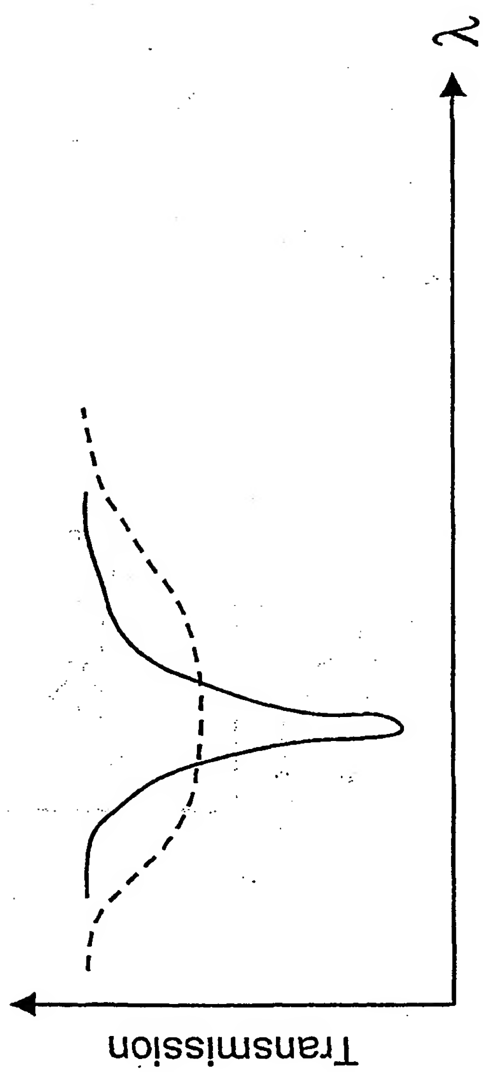

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 02/01186

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G02F 1/295, H04J 14/02, H04B 10/24, G02B 6/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G02F, G02B, H04B, H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5777763 A (TOMLINSON,III.W.J.), 7 July 1998 (07.07.98) --	1-46
A	WO 9848303 A1 (RENISHAW PLC), 29 October 1998 (29.10.98), abstract --	1-46
A	JP 10078515 A (SUMITOMO ELECTRIC IND LTD) 1998-06-30 (abstract). (on line) (retrieved on 2002-05-09). Retrieved from EPO PAJ/JPO Database -- --------	1-46

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 October 2002	25-10-2002
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Erik Westin /itw Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/SE 02/01186

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5777763 A	07/07/98	NONE	
WO 9848303 A1	29/10/98	GB 9707953 D	00/00/00
		GB 9709859 D	00/00/00